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Historical changes in rainfall pattern in the Eastern Cape Province, South Africa

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Abstract The paper investigates the problem of temporal changes in rainfall characteristics at the scale of one administrative and geographic region of South Africa—the Eastern Cape Province—using historical daily records. Rainfall stations selected represent different parts of the province and have the longest observation periods. For each station the following characteristics have been extracted and analysed for possible trends: (a) annual rainfall totals; (b) annual number of days with rain; (c) annual maxima of daily rainfall; (d) annual number of days with daily rainfall exceeding certain threshold levels; (e) annual mean daily rainfall; (f) annual median daily rainfall. Preliminary results indicate that while the time series of annual rainfall totals remain stationary, the number of raindays is progressively decreasing in many records. This tendency is especially pronounced in humid parts of the province and during the last 50 years. This is often accompanied by the increasing trend in daily rainfall means. Other contributing processes detected at fewer stations in the recent period include the increasing frequency of maximum daily rainfall and increasing median rainfall.

INTRODUCTION

The existing water resource management practices as well as the methods of hydrological calculations used in engineering practice are based on the concept of stationarity of the underlying hydrological time series. The latter is effectively a derivative of the corresponding rainfall time series. Therefore, any temporal changes in rainfall characteristics could have serious implications for hydrological engineering and water resource management.

Climatic changes which may result from an increase in atmospheric greenhouse gases have been the subject of many studies. However, such studies are normally conducted at the scale of the large territories/continents, focus on the changes in long-term means of climatic characteristics and are often based on the results of simulations obtained using climatic models. The studies focusing on historical meteorological records normally investigate the interannual variability and cyclicity of meteorological variables while the pattern of daily events is frequently ignored.

No commonly agreed scenario of the rainfall pattern change for South Africa currently exists. Some studies predict the increase in the frequency of extreme daily rainfall events with no or minor changes in annual rainfall totals (Mason & Joubert, 1997), while others indicate the possibility of decrease in average daily rainfall (Huwitson, 1997). No attempt known to the author, has been made in the country to analyse the historical records of daily rainfall in order to identify the changes in its

temporal variability. This paper addresses the problem of temporal changes in daily rainfall characteristics at the scale of one administrative and geographical region—the Eastern Cape Province of South Africa—and is based on several long historical rainfall records.

DATA AND METHODS

The Eastern Cape Province of South Africa lies to the south and southwest of Lesotho (Fig. 1). The province includes several climatic zones with mean areal precipitation (MAP) varying from 300 mm (in the western inland parts of the region) to more than 1000 mm (in the north-eastern and coastal areas). The rainfall is mostly of frontal origin, although a strong orographic effect is present in the northeastern regions along the southern Drakensberg mountains.

There is a large number of rainfall stations in the province, but for the purpose of this study only the stations with the longest records (70–100 years and longer) have been selected. The majority of these records start in the 19th century and therefore the records normally exceed 100 years. Such long records should insure the possibility of detecting climatic trends (if those exist). The total number of stations initially considered for this study was over 40, but several stations with a large number of gaps due to missing data have been excluded from the analysis. The final number of rainfall stations selected is 23. Some details of these stations are summarized in Table 1.

The following rainfall characteristics have been extracted for each station:

- annual rainfall totals;
- annual number of days with rainfall;
- annual number of days with missing data;
- annual mean rainfall per day with rain;

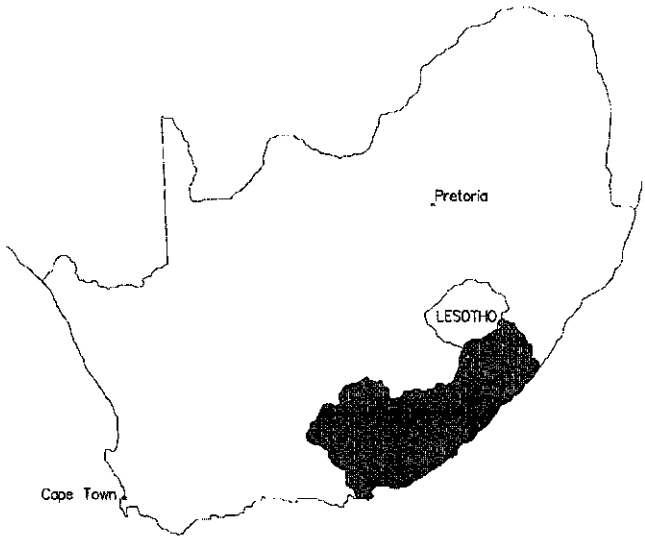

Fig. 1 A schematic map of South Africa showing the location of the Eastern Cape Province.

Table 1 Selected rainfall stations and general rainfall characteristics.

Gauge code	Start year	End year	MAP (mm)	CV	Daily max. (mm)	Mean raindays	Daily mean (mm)	% days missing
0034381	1881	1996	802	0.27	205	89	8.99	44.9
0036729	1885	1996	290	0.28	290	65	9.52	1.65
0037696	1882	1996	607	0.32	167	74	8.21	16.7
0056139	1877	1996	388	0.33	152	42	9.15	5.00
0059722	1880	1996	751	0.33	405	97	7.77	33.3
0057048	1877	1996	667	0.26	185	86	8.36	2.39
0073871	1890	1996	272	0.36	105	33	8.22	3.26
0076133	1877	1996	590	0.30	149	68	8.67	1.16
0078755	1885	1996	1169	0.20	228	98	11.9	2.18
0079215	1899	1996	886	0.22	228	98	11.5	2.27
0079396	1899	1996	807	0.27	420	90	8.99	2.95
0079632	1885	1996	920	0.20	420	108	8.53	2.37
0079730	1909	1996	886	0.22	213	86	10.1	5.84
0080694	1884	1991	694	0.28	198	78	8.88	4.43
0095823	1890	1996	376	0.33	161	38	9.68	4.43
0096101	1888	1996	279	0.32	123	37	7.59	0.25
0096272	1899	1996	306	0.33	81	39	7.77	1.58
0100329	1882	1996	964	0.19	135	90	10.7	2.94
0123063	1885	1996	471	0.29	106	46	10.2	2.00
0125880	1890	1996	790	0.45	400	71	11.1	2.76
0127298	1892	1996	731	0.43	400	74	9.89	0.72
0152475	1919	1996	1152	0.22	280	91	12.7	2.22
0238468	1920	1996	917	0.30	168	82	11.2	4.15

- annual maximum of daily rainfall;
- annual median daily rainfall (for days with rainfall);
- annual number of days above several threshold rainfall values.

For general comparison of the data between stations and for selection of the threshold rainfall values for further analysis, several average rainfall characteristics have also been estimated for each gauge for the entire record period. Those include mean annual precipitation (MAP), coefficient of variation of annual rainfall totals (CV), absolute maximum daily rainfall recorded, mean annual number of raindays per year (estimated as the total number of days with rain in the record divided by the number of years), long-term mean daily rainfall (per day with rain; calculated as MAP divided by the mean annual number of days with rain) and the percentage of days with missing data. The latter characteristic was indicative of the quality of the original data.

The C-coded PC based computer program has been written to facilitate the analysis. It allows all time series and general rainfall characteristics to be extracted from the selected raw data file (one rainfall station at a time) and provides a number of time series display facilities. The program allows the threshold rainfall values to be expressed in % of either the long-term daily mean or absolute maximum rainfall. All resultant time series may be written to a file for further analysis using the spreadsheet package for example.

The extracted annual daily rainfall characteristics have been plotted as a time series and a trend line (a line of the linear regression of the analysed variable with time) has

DISCUSSION

With the exception of only one station (0079730), rainfall records were found to demonstrate no pronounced temporal decreasing or increasing trends in annual rainfall totals. Since rainfall stations selected represent different parts of the province with MAP ranging from 290 to 1169 mm (Table 1), it may be concluded that temporal variability of annual rainfall at the provincial scale (and consequently, the spatial variability of the MAP) remains unchanged and so far unaffected by climatic changes.

However, a noticeable decreasing trend in the annual number of days with rain has been detected in the majority of analysed records. At some rainfall stations the number of raindays is decreasing gradually throughout the whole period of record (Fig. 2). Observations at other stations demonstrate a pronounced decrease in the number of raindays during the last 50 years (Fig. 3). The number of days with missing data is normally larger at the beginning of the record period than in the

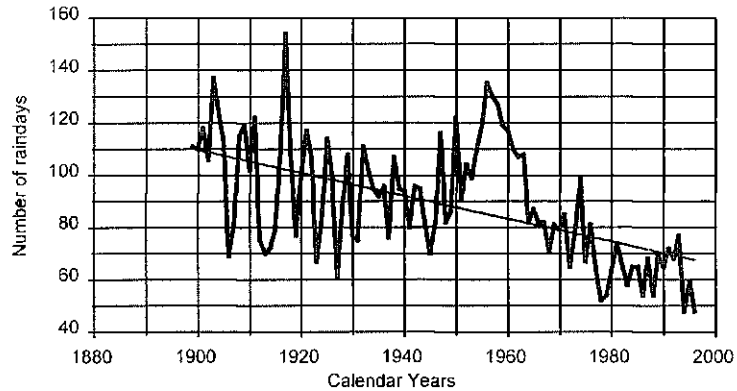

Fig. 2 Annual time series of the number of days with rain at gauge 0079396.

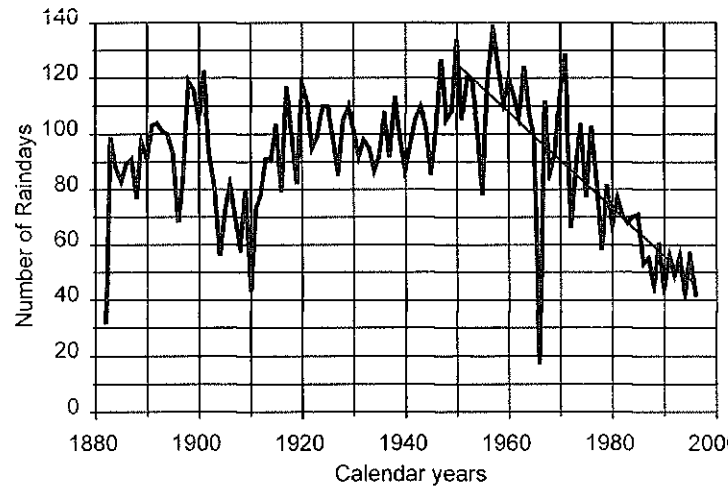

Fig. 3 Annual time series of the number of days with rain at gauge 0100329.

recent years. Therefore, even assuming that all days with missing data were the days with rain, these decreasing trends cannot be neutralized or reversed. The detected trends are especially pronounced in more humid parts of the province, where MAP exceeds 600–700 mm. However, some stations in the drier regions (e.g. 0036729) also demonstrate a similar pattern.

It has been suggested that since annual total rainfall is stationary, one possible consequence of the decreasing annual number of days with rain may be the increased number of days when rainfall exceeds certain (high) threshold rainfall. In other words, the smaller the number of raindays in a year, the larger number of days among them should be the days with high rainfall. This hypothesis has been investigated using a number of different threshold rainfall values for each gauge. The thresholds have varied from very high (50% of the absolute recorded daily maximum rainfall) to relatively low values (25% of the mean daily rainfall). The absolute recorded maximum is normally more than an order of magnitude higher than the long-term

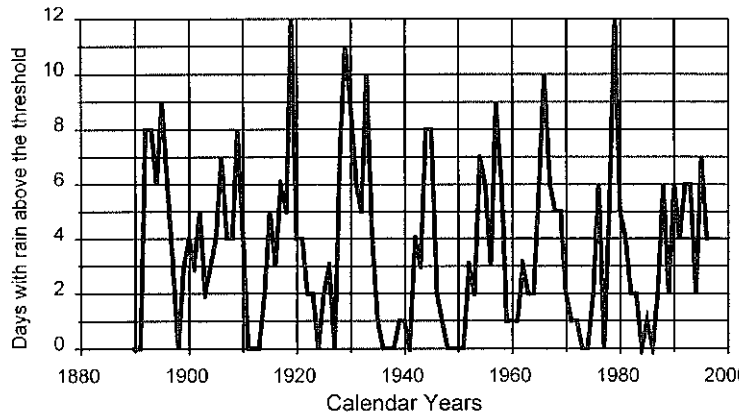

Fig. 4 Annual time series of a number of days with rainfall exceeding 50% of the mean at gauge 0125880.

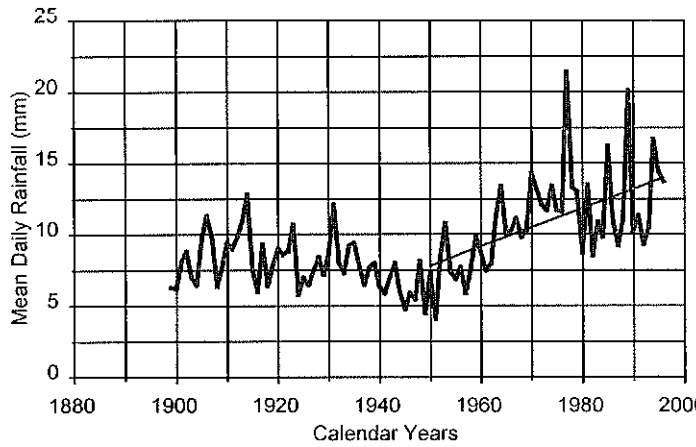

Fig. 5 Annual time series of mean daily rainfall totals at gauge 0079396.

mean daily rainfall (Table 1). Analysis of the annual time series of maximum daily rainfall also demonstrated that at several stations there is a large difference between the absolute daily maximum rainfall and the "second largest" daily rainfall maximum. For that reason, most of the thresholds used have grouped around the long-term mean daily rainfall value (from 25% to 500% of the mean).

It has been found, however, that only a few rainfall stations demonstrate a minor increase in the number of days with "high rainfall". In the majority of cases the time series of extracted number of days above selected thresholds have appeared to be stationary (Fig. 4). No common daily rainfall threshold for all stations (above which the increasing trend in a number of high rainfall days exists) has been identified which implies that changes in daily rainfall which accompany the detected decrease in the number of raindays, may be of a much more complex nature and that not only maximum daily rainfall has to be investigated in this regard.

Consequently, the next step of the study has been the analysis of annual time series of maximum daily rainfall, mean daily rainfall (per day with rain) and median daily rainfall (for days with rain). Because of the positive skewness of the distribution of daily rainfall values in each year, the median daily rainfall in a year is smaller than the mean. Therefore, the median daily rainfall has been considered as an indicator of the "low daily rainfall" values.

The increasing trends in mean daily rainfall have been discovered at several rainfall stations. These trends are normally present in the record during the last 50 years (Fig. 5). During the same period, some other records appeared to demonstrate the increased variability of daily rainfall (mostly due to the increased frequency of maximum daily rainfall). Figure 6 illustrates that, for example, the high rainfall threshold of 100 mm day^{-1} has been exceeded 14 times since 1940 (in 14 years out of 56), while in the first half of the record period (prior to 1940) the same threshold has been exceeded only 5 times. Some records have demonstrated the increasing trend in the annual time series of the median daily rainfall (Fig. 7), which effectively indicates that low non-zero daily rainfall totals are increasing as the number of raindays is decreasing.

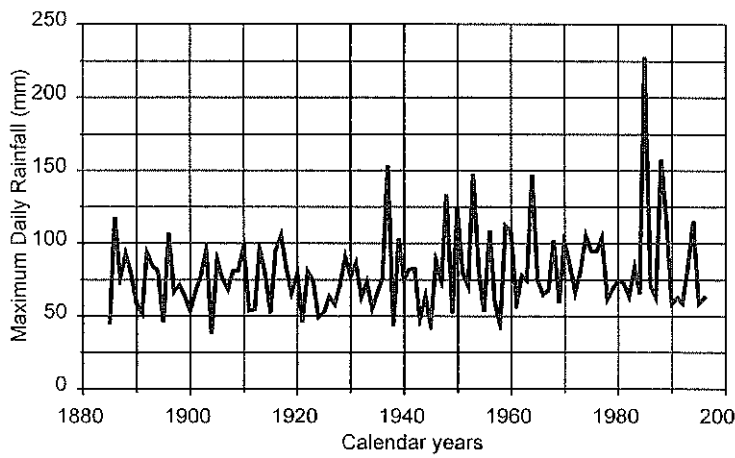

Fig. 6 Annual time series of maximum daily rainfall at gauge 0078755.

In general, no common mechanism of daily rainfall changes may be identified on the basis of the records analysed. The changes in different parts of the province are driven by one of the three described processes or their combinations.

CONCLUSIONS AND FUTURE RESEARCH

The longest historical rainfall records in the Eastern Cape Province of South Africa analysed in this study do not demonstrate the increasing or decreasing trends in mean or variance of annual rainfall totals. At the same time, the annual number of days with rain has been found to be decreasing at the majority of rainfall stations. This decreasing trend manifests itself better in the humid parts of the province where MAP exceeds 600–700 mm. The trend is more pronounced during the last 50 years and is often accompanied by the increasing annual mean daily rainfall (per day with rain). The increased frequency of high rainfall events have also been detected, but only at the few rainfall stations. At the same time, the increasing annual median daily rainfall at several stations indicates that low non-zero daily rainfall totals are increasing with the decrease in the number of raindays. The results presented in this paper are preliminary and more research is necessary regarding the direction of temporal changes in daily rainfall pattern in the province.

Since the decreasing trend in the number of days with rain is particularly strong during the last 50 years, more observed records (starting in 1930s–1950s) may be analysed. This would increase the information base of the study. The study at this stage did not address the problem of temporal variation of daily rainfall within particular months/seasons. However, some studies predict the change in seasonal daily rainfall characteristics (Huwitson, 1997), and therefore, the problem of detecting such changes from historical records should also receive attention. Additional information on the temporal changes in rainfall characteristics (and

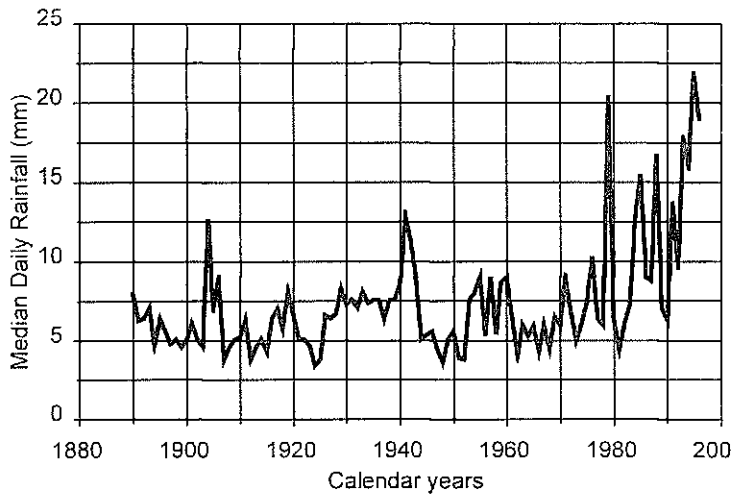

Fig. 7 Annual time series of median daily rainfall at gauge 0125880.

particularly, in extreme rainfall) may possibly be obtained from the analysis of continuous rainfall records with a time step smaller than one day.

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